

REMARKS

Reexamination and reconsideration in light of the foregoing amendments and the following remarks is respectfully requested.

Claims 1-20 are pending in this application. Claims 19 and 20 have been withdrawn from consideration due to a restriction requirement. Applicant appreciates the indication of allowability of claims 5, 9 and 11. However, claim 9 has been amended to correct an informality. The term "required pattern" has been changed to "a required pattern" to be consistent with the language in allowed claims 5 and 11. This amendment should have no bearing on the allowance of the claim. Claims 1, 13 and 15-17 have been amended to further define the invention. Support for the amendments to the claims can be found in Figs. 4F to 4J and at page 10, line 1 to page 11, line 8; page 12, line 18 to page 13, line 28; page 15, lines 17-25; page 16, lines 12-22; and page 24, lines 1-27. None of the amendments introduce new matter or should not require further search or consideration by the Examiner. Accordingly, entry of the amendment is respectfully requested.

Applicant notes the Examiner's acceptance of the drawing changes submitted on March 27, 2001. Applicant further notes the Examiner's acknowledgment of Applicant's claim for foreign priority under 35 U.S.C. § 119 and receipt of the certified priority document.

REJECTION OF CLAIMS 1-4, 6-8 AND 10

Claims 1-4, 6-8 and 10 stand rejected under 35 U.S.C. 103(a) as being unpatentable over Tyagi et al. ("An Isoplanar Isolation Technology for SiC Devices Using Local Oxidation" pages 2188-2191) in view of Ueno et al. (U. S. Patent No. 6,265,326 B1). According to the Examiner, with respect to claim 1, Tyagi et al. "teaches depositing a silicon film over a SiC substrate; delineating the silicon film into a required pattern so as to expose a surface of the SiC substrate;

and annealing the SiC substrate to selectively grow a localized thermal film above the SiC substrate (pages 2188-2191)." The Examiner concedes that Tyagi et al. do not "teach annealing the SiC substrate in a water rich ambient." For this deficiency, the Examiner relies on Ueno et al. According to the Examiner, Figs. 1-4 and the related description of these figures in Ueno et al. disclose "thermally growing an oxide layer in a water rich environment to increase the speed of formation of a thermal oxide (abstract)." From these findings, the Examiner concludes that "[i]t would have been obvious to one having ordinary skill in the art at the time the invention was made to anneal the SiC substrate of Tyagi in water rich vapor, as taught by Ueno, since it would increase the speed of formation of a thermal oxide." Applicant respectfully disagrees with the Examiner's analysis and traverses the rejection.

Tyagi et al. is directed to local oxidation of silicon (LOCOS) and a modification of LOCOS method. In the LOCOS method, the silicon nitride layer acts as a barrier to the diffusion of the oxidant, preventing oxidation in selected region of silicon not covered by silicon nitride. The LOCOS method disclosed by Tyagi et al. has a well-known problem, namely, the formation of a bird's beak, which is characterized by a bump of silicon oxide having a gradually narrowing oxide tail encroaching into a region under the silicon nitride layer. In addition to the bird's beak problem, Tyagi et al. disclose another disadvantage with the LOCOS method. The nitride mask cracks and fails at high temperature due to the formation of high-density pinholes. In the paragraph bridging pages 2188 and 2189, Tyagi et al. disclose that a nitride mask tends to fail because the oxidation rate for SiC is much smaller than that of silicon.

In order to avoid the problems associated with mask failure and cracking, Tyagi et al. propose on page 2189, second column, et seq., to modify the LOCOS method and use another

isolation technology called the "the field poly process." See Fig. 4 of the reference. As shown in Fig. 4 (b), a thin stress relief oxide layer (pad oxide) is grown by oxidation on the surface of a 6H-SiC wafer, a polysilicon layer is deposited on the stress relief layer, thin sacrificial oxide layer is thermally grown on the polysilicon, and a silicon nitride layer is deposited on the sacrificial oxide layer. The silicon nitride layer acts as the barrier to the diffusion of the oxidant. The silicon nitride layer is then delineated to define isolating field region. The polysilicon is selectively oxidized to provide thick field oxide film as Fig. 4 (c).

Because the polysilicon can be oxidized much faster than SiC, the "field poly process" can avoid the problems associated with mask failure and cracking. However, the "field poly process" must employ a silicon nitride layer. Fig. 4(d) shows the configuration of the bird's beak, in which the thick field oxide film serving as the isolating field region surrounds a thin pad oxide film at the central portion. The configuration in Fig. 4(d) shows the silicon nitride layer covering the central portion to protect it from oxidization. In the "field poly process," the difference between the oxidation rate for polysilicon and that of silicon nitride layer is employed to achieve the selective oxidization. Therefore, to grow thick field oxide film on isolating field region, the surface of 6H-SiC wafer must be covered by the polysilicon, and the silicon nitride layer must cover the active area of the wafer surface so that the silicon nitride layer can serve as an anti-oxidation mask or a barrier to the diffusion of the oxidant.

In contrast, the present invention as recited in claim 1 requires the use of selective oxidization of silicon, which employs the difference between an oxidation rate for SiC and the oxidation rate for silicon, thereby eliminating the need to use a silicon nitride film as the oxidation protection mask. In particular, claim 1 requires:

- (a) depositing a silicon film above a SiC substrate;
- (b) delineating the silicon film into a required pattern so as to expose a part of a surface of the SiC substrate; and
- (c) selectively oxidizing the delineated silicon film, so as to grow a localized thermal oxide film in the required pattern above the SiC substrate by exposing simultaneously the part of the surface of the SiC substrate and all of the delineated silicon film to a water rich ambient.

The Tyagi et al. reference is silent with regard to the difference between an oxidation rate for SiC and that for silicon since the ratio of the oxidation rate of polysilicon and that of silicon nitride plays important role in Tyagi et al. "field poly process" because the silicon nitride film serves as the oxidation protection mask. At page 2190, first column of the reference, Tyagi et al. state that ratio of the oxidation rate of polysilicon to that of SiC is 30 and that ratio of the oxidation rate of polysilicon to that of silicon nitride is 60 at a temperature of 1100° C. However, with respect to the present invention, the ratio of oxidation rate of polysilicon to that of SiC is not a fixed value, but must depend on the H₂O partial pressure as evidenced by Fig. 2 in the present invention disclosure.

Fig. 2 is graph representing the relationship between H₂O partial pressure and the thickness of a silicon oxide film thermally grown at 1100° C for 7 hrs. The broken line denotes the oxide film thickness grown on the surface of a silicon substrate and the solid line denotes the oxide film grown on the surface of a SiC substrate. The oxide film thickness formed on the silicon substrate increases as the H₂O partial pressure increases to a H₂O rich regime, i.e. when the H₂O becomes 1. On the other hand, the oxide film thickness on the surface of the SiC substrate has the highest oxidation rate at a H₂O partial pressure of about 0.55, and as the H₂O

partial pressure increases to a value of more than 0.95, there is a significant decrease in the formation of the oxide film. At the highest oxidation rate for forming an oxide film on SiC, the rate of oxidation would be about 50 nm/7 hrs while the rate of oxidation of a silicon substrate would be about 1500 nm/7 hrs at a H₂O partial pressure of 0.55. Therefore, ratio of the oxidation rate for forming an oxide film on a silicon substrate to that of a SiC substrate at a H₂O partial pressure about 0.55 would be 30 (1500/50). As shown in Fig. 2, the ratio of oxidation rate of polysilicon to the oxidation rate of SiC in the claimed "water rich ambient" which is larger than 30. For example, the ratio of oxidation rate of polysilicon to the oxidation rate of SiC is greater than or equal to 60 for a H₂O partial pressure greater than 0.95. A "water rich ambient" is a high H₂O partial pressure ambient, i.e., where the oxidation rate ratio is greater than 60. See page 6, lines 18-19 and page 16, lines 12-22 of the specification. Tyagi et al. do not teach or suggest the relationship between the oxidation rate of silicon and that of silicon carbide. Accordingly, a person having ordinary skill in the art would not have been led to expect a SiC substrate and a silicon layer in a "water rich ambient" to selectively oxidize the silicon layer as required by the claim 1.

In addition to the above, Tyagi et al. do not disclose or suggest the claimed step of delineating the silicon film into a required pattern so as to expose a part of a surface of the SiC substrate. For example, the required pattern may correspond to the pattern surrounding the active area. In the portion where the active area is to be formed, the silicon film is removed to expose the surface of the SiC substrate. The claimed method uses the selective oxidization of silicon ascribable to the difference between the oxidation rate for SiC and the oxidation rate for silicon. In contrast, the "field poly process" disclosed by Tyagi et al. requires depositing a

silicon nitride layer to cover the portion where the active area is to be formed to serve as the anti-oxidation mask. The present invention does not have this requirement. Therefore, a person having ordinary skill in the art would not have been led by the teachings of Tyagi et al. to expose an active region of the SiC substrate before the oxidation step.

Furthermore, Tyagi et al. fail to teach or suggest the claimed step of selectively oxidizing the delineated silicon film, so as to grow the localized thermal oxide film in the required pattern above the SiC substrate by exposing simultaneously the part of the surface of the SiC substrate and all of the delineated silicon film to a "water rich ambient." In the "field poly process" of Tyagi et al., the silicon nitride layer is delineated so as to define the reverse pattern of the claimed required pattern. The reverse pattern corresponds to a pattern surrounded by the claimed required pattern, and because the silicon nitride layer covers the area of the reverse pattern, it is impossible to expose simultaneously the part of the surface of the SiC substrate and all of the delineated silicon film to claimed water rich ambient. Further, as shown in Fig. 4(c) of Tyagi et al., since a part of the polysilicon remains unoxidized above the active area because of the silicon nitride layer, it is evident that all of the delineated silicon film is not exposed to claimed "water rich ambient" and oxidized so as to define the localized thermal oxide film into the required pattern. In the "field poly process" of Tyagi et al., the silicon nitride layer, the unoxidized polysilicon disposed just under the silicon nitride layer and the pad oxide disposed just under the unoxidized polysilicon, respectively, which are disposed on the active area, must be removed so as to obtain the localized thermal oxide film having the required pattern by the technique of Tyagi et al. as shown in Figs. 4(c) to 4(e).

For all of the foregoing reasons, the "field poly process" of Tyagi et al. is clearly distinguishable from method recited in claim 1.

The secondary reference, Ueno et al., does not cure the deficiencies in Tyagi et al., since both references, taken alone or in combination, fail to teach or suggest claimed the step of delineating the silicon film into required pattern so as to expose a part of the surface of the SiC substrate and both, taken alone or in combination, fail to show claimed step of exposing simultaneously the part of the surface of the SiC substrate and all of the delineated silicon film to claimed "water rich ambient" with an expectation that silicon can be selectively oxidized. Ueno et al. is concerned with controlling the oxidation rate to get the thickest oxide layer in the shortest period of time. This teaches away from the present invention, which is directed to minimizing or eliminating the oxidation of the exposed SiC surface. While Figs. 1 and 4 of the Ueno et al. reference show the difference in the oxidation rate of silicon carbide to that of silicon, there is no suggestion in Ueno et al., taken alone or in combination with Tyagi et al. that a difference between the oxidation rates can be used to selectively oxidize as required by claim 1 of the present. This suggestion could only have come from Applicant disclosure.

Although the Examiner contends that Ueno et al. disclose thermally growing an oxide layer in a "water rich ambient" to increase the speed of formation of a thermal oxide, this does not suggest selective oxidation as required by claim 1. While Fig. 4 of Ueno et al. shows the dependence of the thickness of oxide film formed by thermal oxidation of silicon, it does not show the dependence of the thickness of oxide film formed by thermal oxidation of SiC. At col. 4, lines 41-45 of the reference, Ueno et al. state that it is too dangerous to control the partial

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pressure of water vapor to 1.0. Therefore, Ueno et al. teaches away from using high partial pressure of water vapor.

Moreover, Ueno et al. is silent with respect to the claimed step of delineating the silicon film into a required pattern so as to expose a part of a surface of the SiC substrate. Also, Ueno et al. fail to show claimed step of selectively oxidizing the delineated silicon film, so as to grow a localized thermal oxide film in the required pattern above the SiC substrate by exposing simultaneously the part of the surface of the SiC substrate and all of the delineated silicon film to a "water rich ambient" as required by claim 1 of the present invention.

For all of the reasons given above, the combined teachings of Ueno et al. and Tyagi et al. as suggested by the Examiner would not have led a person having ordinary skill in the art to the claimed invention since both references (i) fail to show claimed step of delineating the silicon film into required pattern so as to expose a part of the surface of the SiC substrate and (ii) fail to show claimed step of exposing simultaneously the part of the surface of the SiC substrate and all of the delineated silicon film to claimed "water rich ambient." Furthermore, since Tyagi et al. pertain to the modification of the LOCOS method, the ratio of oxidation rate of polysilicon to that of SiC is not important, but the ratio of oxidation rate of polysilicon to that of silicon nitride is important. Ueno et al. does not cure this deficiency. Accordingly, for this reason also, there is no motivation to combine the teachings of Ueno et al. and Tyagi et al. to arrive at the claimed invention.

For all of the foregoing reasons, the Examiner has not established a *prima facie* case of obviousness in the rejection of claim 1 over the combined teachings of Tyagi et al. and Ueno et

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al. Since claims 2-4, 6-8, 10 and 12 are ultimately dependent on base claim 1, it is respectfully requested that the rejection of claims 1-4, 6-8, 10 and 12 be reconsidered and withdrawn.

REJECTION OF CLAIMS 13-18

Claims 13-18 stand rejected under 35 U.S.C. 103(a) as being unpatentable over Palmour (U. S. patent 5,459,107) in view of Ueno et al. According to the Examiner, Palmour discloses, in Figs. 1A-4C and related text, "forming a gate oxide film on a surface of a SiC substrate; and annealing the gate oxide film." The Examiner concedes that "Palmour does not show wherein the annealing takes place in a water rich environment at a temperature equal to or lower than the substrate temperature at which the gate oxide film is formed and that that temperature is of about 700°C-1050°C." For this deficiency the Examiner relies on Ueno et al. According to the Examiner, "Ueno discloses that to increase the rate of speed of formation of a thermal oxide film of a silicon carbide semiconductor device, the partial pressure of water is controlled within a range of 0.1 to 0.95 (abstract) at a temperature of about 1000°C (column 3)." From these findings the Examiner concludes that "[i]t would have been obvious to one having ordinary skill in the art at the time the invention was made to anneal in a water rich environment at a temperature equal to or lower than the substrate temperature at which the gate oxide film is formed and that that temperature is of about 700°C-1050°C in the invention of Palmour, since as taught by Ueno to increase the rate of speed of formation of a thermal oxide film of a silicon carbide semiconductor device, the partial pressure of water is controlled within a range of 0.1 to 0.95 at a temperature of about 1000°C." The Examiner further concedes that "Palmour in view of Ueno does not disclose so as to reduce interface density between the gate oxide and the SiC substrate," but concludes that the "recited results would be obtained because the same materials

are treated in the same manner as in the instant invention." Applicant respectively traverse this rejection.

Applicant's invention is directed to method for manufacturing the SiC device capable of providing an improved gate oxide film, embracing smaller interface state densities. To that end, the claimed method recited in claim 13 comprises:

- (a) forming a gate oxide film on a surface of a SiC substrate in O₂ rich ambient; and
- (b) annealing said gate oxide film in a water rich ambient at a substrate temperature equal to or lower than the substrate temperature at which the gate oxide film is formed so as to reduce interface density between the gate oxide film and said SiC substrate, after stopping the supply of the O₂ rich ambient, the H₂O partial pressure of the water rich ambient is larger than the H₂O partial pressure of the O₂ rich ambient.

Palmour does not disclose or suggest the claimed step of annealing claimed gate oxide film in a "water rich ambient" after stopping the supply of the O₂ rich ambient. Further, the reference does not teach or suggest that the H₂O partial pressure of the "water rich ambient" is larger than the H₂O partial pressure of the "O₂ rich ambient." The "O₂ rich ambient" is defined at page 9, lines 1-5 of the specification as follows:

Here, "the oxygen added ambient" is defined as the oxidation ambient in which the O₂ gas is added so that the H₂O partial pressure becomes below 0.95. Ob [sic, Of] course, "the oxygen added ambient" embraces the O₂ rich ambient and the perfect O₂ ambient, which contains 100% O₂ partial pressure."

As for Ueno et al., this reference does not make up for the deficiencies of Palmour. Ueno et al. do not disclose or suggest of claimed step of annealing claimed gate oxide film in a "water rich ambient" after stopping the supply of the "O₂ rich ambient." The reference also does

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not disclose that "the H₂O partial pressure of the water rich ambient is larger than the H₂O partial pressure of the O₂ rich ambient."

For all of the above reasons, the combined teachings of Ueno et al. and Palmour would not have led a person having ordinary skill in the art to the claimed invention. Accordingly, the Examiner has not establish a *prima facie* case of obviousness in the rejection of claim 13 over the combined teachings of Palmour and Ueno et al. Since claims 14-18 are ultimately dependent on base claim 13, it is respectfully requested that the rejection of claims 13-18 over the combined teachings of Palmour and Ueno et al. be reconsidered and withdrawn.

CONCLUSION

It is submitted that the claims 1-4, 6-8, 10 and 12-18 are patentable over the combined teachings of the prior art relied upon by the Examiner. Accordingly, favorable reconsideration of the claims is requested in light of the preceding amendments and remarks. Allowance of the claims is courteously solicited.

To the extent necessary, a petition for an extension of time under 37 CFR 1.136 is hereby made. Please charge any shortage in fees due in connection with the filing of this paper, including

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extension of time fees, to Deposit Account 500417 and please credit any excess fees to such deposit account.

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